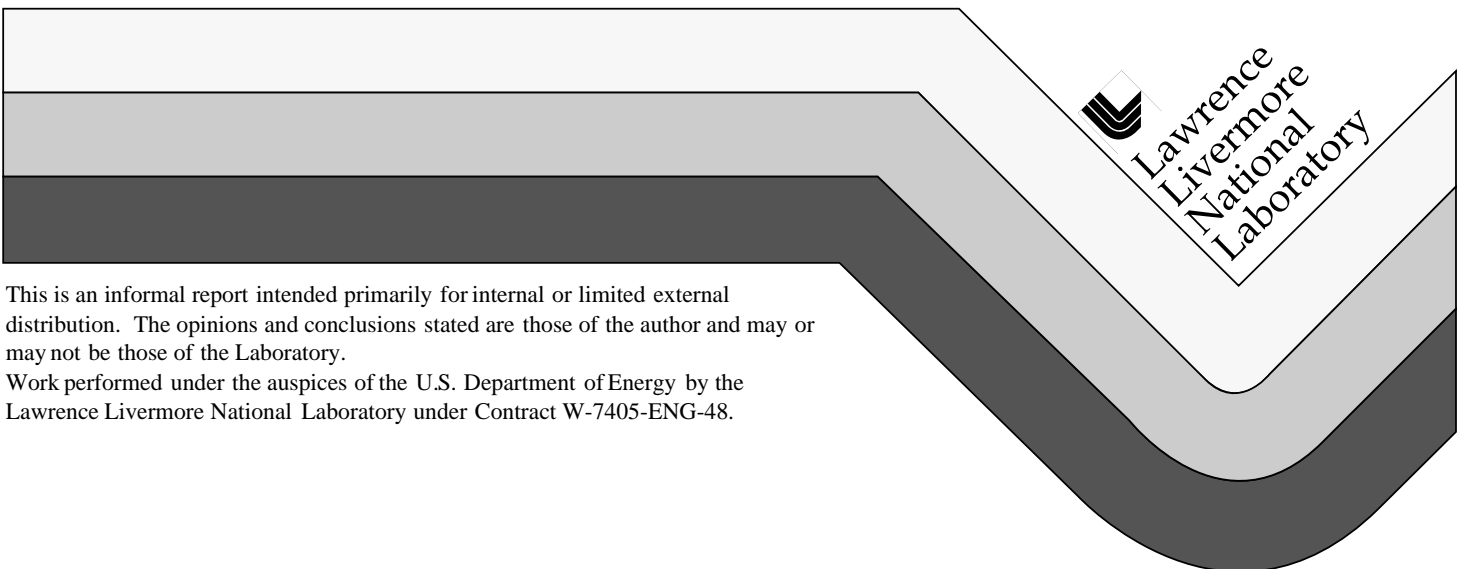


Photonic Doppler Velocimetry

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Photonic Doppler Velocimetry

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We are developing a novel fiber-optic approach to laser Doppler velocimetry as a diagnostic for high explosives tests. Using hardware that was originally developed for the telecommunications industry, we are able to measure surface velocities ranging from centimeters per second to kilometers per second. Laboratory measurements and field trials have shown excellent agreement with other diagnostics.

Introduction

Laser Doppler velocimetry is a powerful diagnostic for the high explosives physics community. The frequency of the Doppler-shifted light provides a direct measure of the instantaneous velocity of a rapidly moving target illuminated by a laser. Light from a multi-mode optical fiber illuminates the target and another multi-mode fiber collects the Doppler-shifted light, allowing spatially-resolved velocimetry information to be obtained.

Currently, physicists perform surface velocity measurements using a technique called, "Fabry-Perot Velocimetry." This system employs free-space Fabry-Perot interferometers and streak cameras for each data channel. These components are costly, complex, require maintenance and operator setup, require a custom-built optical table and occupy a considerable volume. The Fabry-Perot system also uses a large YAG laser whose output is doubled to 532 nm because the streak camera photocathode is insensitive in the infrared region of the spectrum. Although the Fabry-Perot velocimeter yields excellent data, overall channel count will always remain low due to its size, cost, and complexity. As new NTS high explosives facilities become available to experimenters, it will be highly desirable to have many velocimetry data channels available without the cost, complexity, and manpower-intensive setup required for the current diagnostic system.

Our technique uses multi-mode fiber optics, an optical PIN detector, RF electronics, and moderate sample-rate A/D converter technology. All of the components fit into a small chassis. The advantage of using multi-mode fiber is the significant increase in optical light collection from the target compared to that from a single-mode fiber. This advance in laser Doppler velocimetry will enable the fielding of significantly more data channels, greatly improving the spatial-temporal information obtained from this diagnostic at reduced cost, complexity, and experimental footprint.

A simplified version of this diagnostic will permit nanosecond-resolution shock arrival-time measurements by detecting the first incidence of Doppler-shifted light. Such a diagnostic will be very useful on high-fidelity flight tests in W Program. Future versions of this diagnostic could be made sufficiently compact and rugged to be practical for the flight test application.

Figure 1 illustrates the basics of the photonic Doppler velocimetry system. A laser-generated optical carrier propagates through a multi-mode fiber to a probe lens. The probe illuminates the target with the optical carrier. As the target moves towards the lens, the reflected light is Doppler-shifted. The probe lens collects a portion of the Doppler-shifted light and the light propagates back through the multi-mode fiber. The Doppler-shifted light is mixed with a fraction of the original optical carrier in a fiber-optic coupler and is detected by a "square-law" optical detector. Under the appropriate polarization and modal conditions, the "square-law" detector generates an electrical current proportional to the square of the optical fields. For the

Doppler-shifted light, this corresponds to a beat frequency proportional to the instantaneous velocity of the target.

At high velocities, the beat frequency is too high to record directly on a transient digitizer. To overcome this limitation, we use a microwave phase discriminator to measure the frequency-dependent phase shift induced by the Doppler signal. Recording of the phase discriminator data is accomplished using a digitizer having a modest sampling rate.

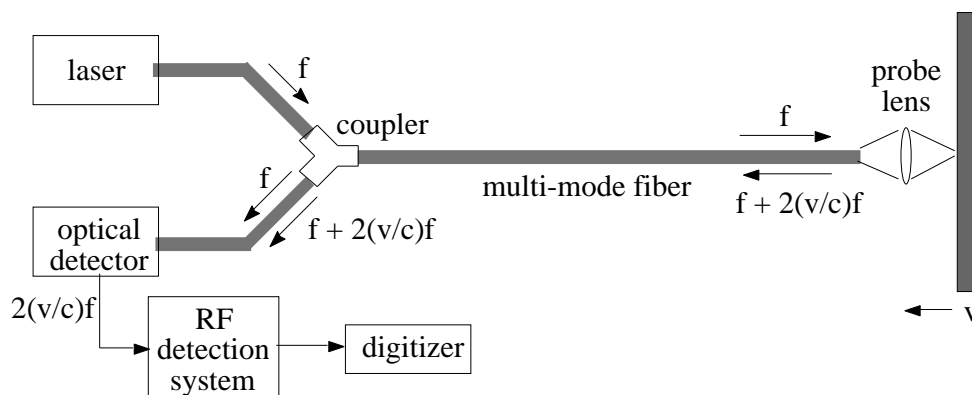


Figure 1. Basic block diagram of the photonic Doppler velocimetry system.

Progress

In the past year, our efforts have focused on laboratory experiments and field trials.

The target for our first refereed test was a shock-driven copper foil, with the Fabry-Perot velocimeter acting as the referee. As illustrated in Figure 2, the copper foil was in close proximity to a bridge wire, which was driven by a capacitive discharge unit (CDU). Green light from a frequency-doubled YAG laser was focused onto the copper target through a probe lens. The Doppler-shifted light was reflected back through the probe lens and was simultaneously processed by both the Fabry-Perot velocimeter and the photonic Doppler velocimeter. The raw transient digitizer data from the photonic Doppler system is plotted in Figure 3a, and the raw streak camera data from the Fabry-Perot system is shown in Figure 3b. The Doppler beat frequency signal in Figure 3a was converted into frequency versus time, and then into velocity versus time, as shown in Figure 4. Velocity values were hand-digitized from the Fabry-Perot data and then plotted on the same graph in Figure 4. The negative velocity at the end of the data record is consistent with the rebounding of the copper foil after the shock event.

In a later experiment conducted at Site 300, the copper foil target was replaced with an aluminum plate that was driven by high explosives. The remainder of the experimental setup was the same as the setup illustrated in Figure 2. This time, however, the Doppler beat frequency was too high to be recorded directly on a transient digitizer. We used a microwave phase discriminator to measure the frequency-dependent phase shift of the incoming signal. The processed result is plotted with the Fabry-Perot result in Figure 5.

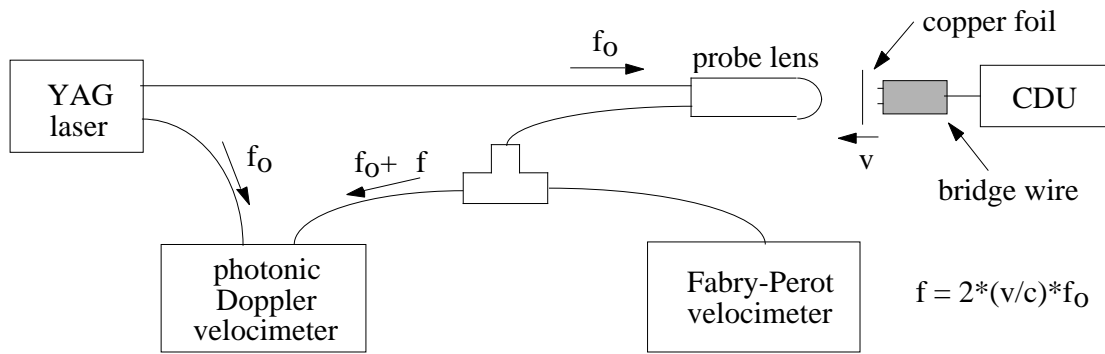


Figure 2. Block diagram of the copper foil velocity experiment.

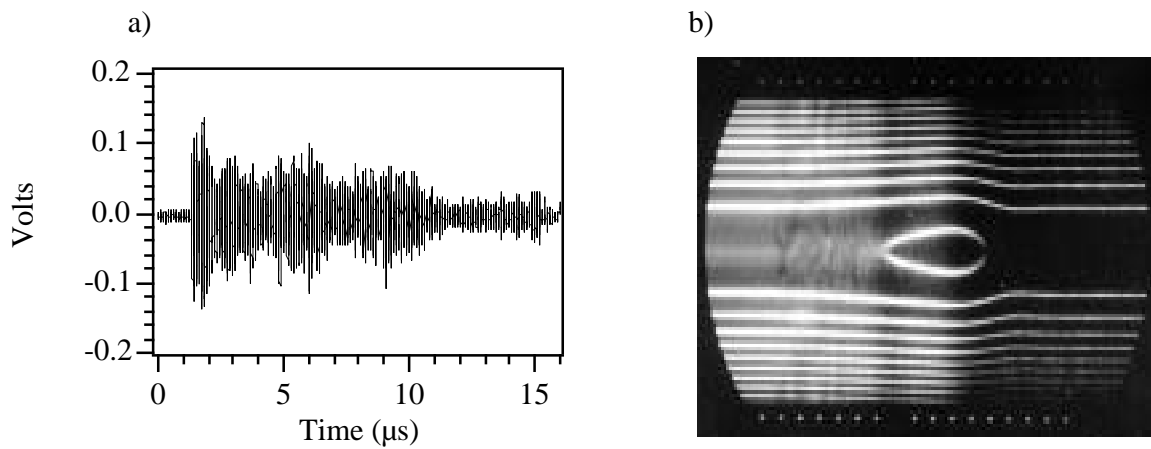


Figure 3. Raw data from the copper foil experiment: a) Photonic Doppler velocimeter, b) Fabry-Perot velocimeter.

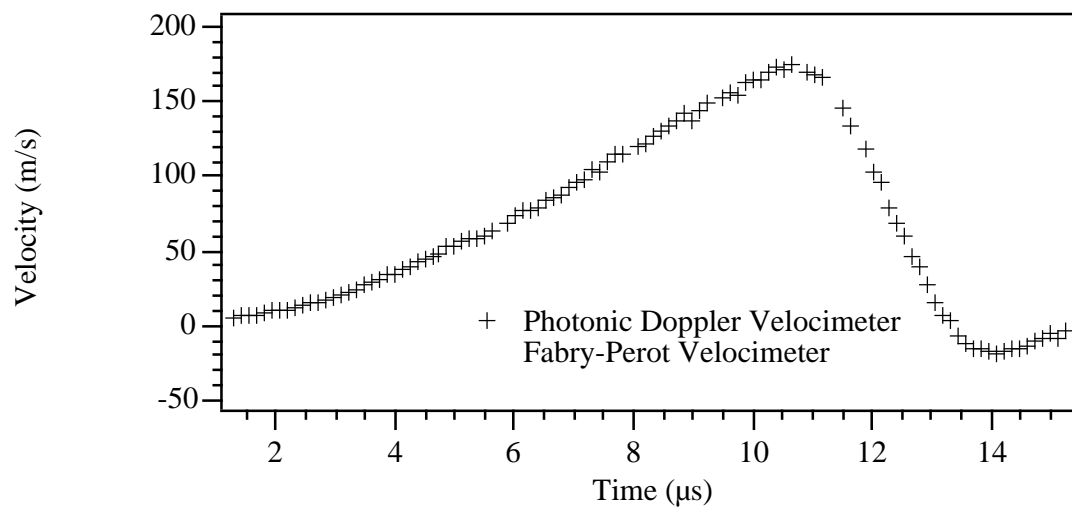


Figure 4. Processed data from the copper foil experiment.

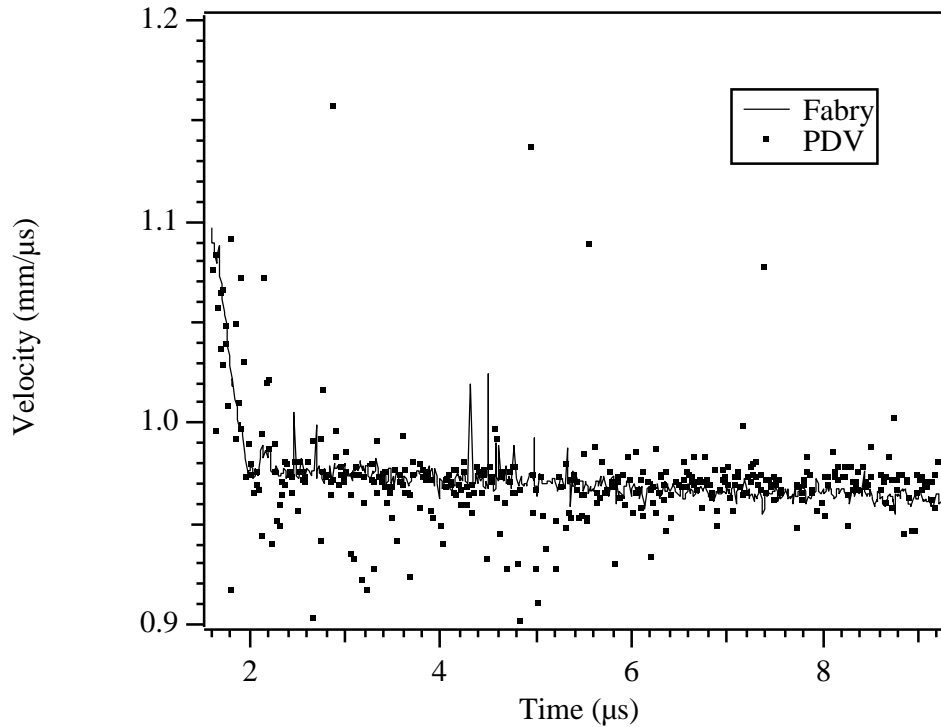


Figure 5. Processed data from the Site 300 experiment.

Towards the end of the year, we conducted a series of measurements in the laboratory using a continuously moving target, which consisted of a speaker driven by an audio oscillator. This setup provided the framework for evaluating system stability and reliability. We discovered that the signal-to-noise ratio varies with time and is adversely affected by physically moving the multi-mode fiber. The likely causes of this phenomenon include: instability of the optical polarization state on the optical detector, modal selective loss, and de-phasing of the optical signals caused by the surface reflection and optical fiber propagation.

Future Work

We plan to conduct further research into the system stability and reliability issues including making detailed measurements of the changes induced in the optical polarization state, the mode populations, and their relative phases by the moving surface and the optical elements in the system. Once we have gained a better understanding of these issues, we will design and build an optimized system. Finally, we will demonstrate the optimized system on an Asay foil experiment.